Evaluating the Prospects and Barriers of Forest Biomass Briquetting Plants in Lebanon based on the Case Studies of Bkessine and Andket

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Abstract

This paper presents the prospects and barriers towards the utilization of biomass briquettes from forestry and agricultural residues for Lebanon, based on the actual implementation of two demonstration projects in biomass briquettes production with an output capacity of 750 tons of briquettes each. We have used quantitative techniques to aid decision makers to understand the economic, environmental and social impacts of forest biomass supply chain and their role is supporting the growth of the sustainable forestry industry. This understanding is gained through simulating the performance of the two demonstration projects under different (investment, operation and policy scenarios) using Monte Carlo simulation techniques to mitigate the risks of uncertainties when assessing the financial performance of biomass briquetting plants.

Keywords

Biomass Briquettes; Sustainable Heating; Biomass; Forestry Residues; Agriculture Residues; Monte Carlo Simulations; Risk Mitigation, Public Private Partnerships.

Contents

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1. INTRODUCTION

There is increasing interest in intensifying the production and use of biomass to replace fossil fuels for the production of heat, electricity, transportation fuel, and various types of chemicals, plastics and other materials (1). One stream with significant potential is biomass briquettes from forestry and agricultural residues. This stream has wide-ranging implications and benefits for countries that choose to support and commercialize biomass briquette value chains. From the reduction of forest fire risks and preservation of natural woodlands (2) (3), rural employment and revenue generation (4) (5), and the provision of sustainable energy sources for heating purposes (in particular) as part of climate change mitigation (6) (7), biomass from forestry and agricultural residues can form a substantial part of an energy mix of any country that is endowed with natural forest resource and/or an extensive agricultural sector.

However, to date the use of biomass is limited in Lebanon. Only 3.5% of Lebanese households are relying on biomass for hot water and space heating. In fact, based on a 600-household survey undertaken by the European Union funded UNDP-CEDRO 4 Project in 2016, these mostly consist of high-income households using firewood in chimneys and rural households using firewood, charcoal, olive husks and biomass briquettes in biomass stoves or other fireplaces (8). On the other hand, approximately 60% of Lebanese householders use electricity for heating, followed by liquid gas (LPG) (25%), and diesel (8%). The overall and best-case scenario for biomass valorization indicated that Lebanon can achieve approximately 37% of its heating demand from biomass resources (9). Table 1 and 2 briefly outline the main characteristics of the most common heating fuels in Lebanon, showing that briquettes sold at whole sale prices ($250/ton) can compete with other heating fuels available in the market however the retail prices ($500/ton), deemed too high, needs to be lower for better market penetration.

Table 1. *Price and Energy characteristics of biomass heating fuels in Lebanon*

Fuel Type	Lower Heating Value (kWh/Kg)	Fuel Price ($/kg)	Fuel Price ($/kWh)	Fuel Demand (kg/year) [1]	Energy Cost ($/year)

[1] Yearly heating demand of a typical Lebanese rural household estimated by, Ruble et al., 2012

Briquette (Bkessine and Andket Plants)	6.33[2]	0.25[3]-0.50[4]	0.04-0.08	467	117-233
Olive Husks	5.22[5]	0.25	0.05	566	142
Wood Dry[6]	5.14	0.25	0.05	575	144

Table 2. *Price and Energy Characteristics of typical heating fuels in Lebanon*

Fuel Type	Heating Value (kWh/L)	Fuel Price ($/L)[7]	Fuel Price ($/kWh)	Fuel Demand (L/year)	Energy Cost ($/year)
Diesel	10.00	0.32 - 0.88	0.032-0.088	295	95-163-260
LPG	12.69		0.07	233	207
Electricity EDL	-		0.10[8]	-	281
Electricity Diesel	-		0.16[9]	-	473

Despite the benefits of using forestry biomass, technical, legislative and economic challenges impede its widespread use. Forest residues are scattered over wide regions which increases the collection, handling and transportation costs. Moreover, there is a variability in the amount and quantity of forest biomass due to forest accessibility during a year, weather conditions, pre-processing requirements, transportation and storage conditions, and competition from other end-users (10). In addition, biomass has lower energy density than other competing fuels. The result is a relatively costlier and logistically complex requirement of procuring, transporting and using forest biomass. Biomass logistics costs typically are in the range of 20 - 40% of delivered fuel costs (11), while in some cases they constitute up to 50% of the delivered fuel costs (12). This situation restricts the competitiveness of forest biomass against other against other energy sources. For these reasons, grant financing is currently being invested in demonstration projects to advance the technology of biomass briquettes and to bring down its costs.

This paper presents the prospects and barriers towards the utilization of biomass briquettes from forestry and agricultural residues for Lebanon, based on the actual implementation of two demonstration projects in biomass briquettes production with an output capacity of 750 tons of briquettes each. We have used quantitative techniques to aid decision makers to understand the economic, environmental and social impacts of forest biomass supply chain (4) and their role is supporting the growth of the sustainable forestry industry. This understanding is gained through simulating the performance of the two demonstration projects under different (investment, operation and policy scenarios). Our aim is to help ensure the knowledge necessary in mitigating undesirable impacts, increase the benefits associated with the use of forest biomass, and ensure the sustainability of replicating new projects. A techno-financial feasibility assessment is conducted, in this regard, along with the attributes and conditions that will improve the replicability of such processes in Lebanon and other countries with similar biomass resources. Furthermore, a market assessment was carried out in order to determine the competitiveness of the briquettes with regard to other fuels being traded in the Lebanese market. The quality of the briquettes was tested to determine their environmental and cost attributes compared to other heating fuels. Finally, the study concludes with a summary of the findings and a set of policy recommendations that are required to further support this technology.

2. The Briquettes value chain in Lebanon: Case Studies of Bkessine and Andket forests

2.1. Forestry and agricultural residues in Lebanon: High energy potential

In 2012, the UNDP-CEDRO project published Lebanon's National Bioenergy Strategy, a study that provided a detailed assessment of relevant biomass resources for the country. A total of twenty-three biomass streams, grouped in accordance with their source of origin (e.g. forestry, wood and paper industries, agriculture, energy crops…) have been identified and prioritized in accordance to four criteria, namely, energy potential, accessibility, sustainability and the presence of the required legal framework(s) (9). Ranking of the various bioenergy streams indicated that 'residues from forestry felling' is the most promising pathway to pursue, followed by 'residues from fruit and olive trees' and 'residues from cereals', respectively (9).

Residues from forestry and agriculture residues make up between 33% and 48% of the total primary energy potential from bioenergy in Lebanon, estimated to be between 13,562 TJ and 21,478 TJ when including second generation energy crops, or 62% - 65% of the total primary energy potential from bioenergy, estimated to be between 9,988 TJ and 11,314 TJ, if second generation energy crops are excluded. The pruning of trees, extraction of residues and shrubs, and fire risk management practices can generate biomass (9). Forests covers about 137,000 hectares or 13% of the Lebanese territory (13) and are showing an increasing trend in the area that they are covering. However, Cedar and Juniper forests are protected under Law 85 for the protection of the forests (amended by Law 558 in 1996). Thus, the

[2] Briquettes from Bkessine and Andket tested at AUB Core Environmental Lab on 13/02/2018, **[see: Annex 1]**
[3] Whole sale prices at factory gate of Bkessine and Andket (1,000 kg bags sold at 250$)
[4] Retail sale prices a different point of sales across Lebanon (10 kg bags sold for $5)
[5] Ruble et al., 2012
[6] Own Site Survey for the cost – Energy Content from https://www.engineeringtoolbox.com/wood-biomass-combustion-heat-d_440.html
[7] Diesel fuel price in Lebanon (2015-2019), fuelprices.com
[8] Average Residential Electricity Tariffs in Lebanon, Edl.gov.lb
[9] Ministry of Trade and Economy website, 2019

potential is only for residues from pine forests and broadleaves forests, equivalent to approximately 82% of total forests of Lebanon. Furthermore, a 4-year frequency for pruning is adopted for Lebanese forests and an assumption that residues form 20% of the total tree volume (9). The total potential from forestry residues will yield 1,378 – 1,771 TJ/year of primary energy (9).

Agricultural residues within the context of biomass briquettes is mainly focused on olive and fruit trees. Olive trees are the most common single crop in Lebanon, they cover around 58.6 thousand hectares of the Lebanese territory (13). Olive tree residue potential is estimated to be between 842 TJ/year to 968 TJ/year, built from assumptions on the density of olive trees, pruning frequencies, heating value of olive tree wood, and moisture content (9). This potential however assumes that all residues are collected for energy production purposes. On the other hand, fruit trees cover 70.8 thousand hectares (13) and produce approximately 950 thousand tons of fruits per year (13). The overall energy potential of residues from pruning of fruit trees was calculated to be between 1,846 – 2,110 TJ per year (9).

2.1.1. Forest inventory and management plan: Sustainable harvesting

In order to ensure the sustainability of biomass harvesting from forestry residues in Lebanon, in 2016, the EU funded UNDP-CEDRO 4 project published Lebanon's National Blueprint for a Sustainable Forest Biomass (14). It served as a guideline report for the development of the forest inventory and management plans for the forest of Bkessine and Andket (15). Bkessine is a village located in the South of Lebanon with a surface area of approximately 500 hectares, of which 220 hectares constitute the largest Mediterranean Stone pine (Pinus pinea) forest in Lebanon (15). The village of Andket is situate in the district of Akkar, North Lebanon and characterized by its large Calabrian pine (Pinus brutia) forest. The management plan was developed for an area corresponding to 1,564 hectares of the Andket forest (14).

The two forest management plans aimed at assessing the forest fuel inventory to accurately estimate the amount of biomass that can be harvested in a sustainable, well planned, and prioritized manner and inclusive of the main traditional and new uses of the forest. The study also identified six different wood fuel types to produce a fire risk map for each forest and suggested several harvesting prescriptions to limit fire risks. These prescriptions cover the priority areas that need to be pruned such as cleaning the forest floor fifteen meters away from the sides of the road and from the forest-agriculture interface, creating fuel breaks along the forest trail, and pruning and thinning techniques reducing tree density to avoid crown fires. Furthermore, the forest harvest plan included financial and technical assessments for pruning activities. The plan identified local capacity gaps in equipment and training of municipality personnel to administer the monitoring and management of pruning activities and biomass production. The plan also identified the role of the different stakeholders involved in the successful implementation of the forest harvesting plan. The Ministry of Agriculture, as one of the main stakeholders in this sector, is responsible in issuing permits for the pruning activities, provide technical support to each municipality and to ensure the proper implementation of the forest laws and regulations. The municipality is responsible to implement the harvesting plan through the hiring of local contractors and to assure that the visitors to the forest follow fire hazard risks. In this regard, all future pruning activities should be coordinated between the different parties to fully adhere by these guidelines. Finally, the study suggested crucial updates to the current legal framework governing the forestry sector especially in terms of forest rejuvenation where the current laws prohibits tree cutting for promoting the growth of a young forest (some forest regeneration activities need to involve the removal of over mature canopy and the artificial regeneration/planting). The younger generation trees would be subjected to different pruning techniques: reducing tree height, widening the crown, cutting non-photosynthetic branches, and improving the wood quality in the lower part of the trunk for future use with more added values (UNDP, 2016a,b).

2.1.2. The current situation of briquette production in Lebanon

Currently, there are five biomass briquetting plants that are in operation in Lebanon, producing in 2017 a total of approximately 1,260 tons of briquettes each year (ref: site visits to the five plants). The UNDP-CEDRO project, based on the recommendations of the National Bioenergy Strategy for Lebanon (9) and the recommendations of the forestry management of Bkessine and Andket (15), has implemented two biomass briquette plants in Lebanon in 2016. The first plant is located in Bkessine plant and relies on residues collected from the 220 hectares Stone pine forest and nearby agricultural residues of olive and vine pruning, while the second biomass briquette plant in Aandket relies on residues collected from the 1,564-hectare Calabrian pine forest and agricultural residues from nearby apple plantations, olive and vine wood residue. Each of the two plants has a 750 tons of briquettes output capacity however several operational factors impede on reaching the desired output capacity. These factors will be discussed in more details in this section. The other three plants in operation in Lebanon are located in (Shouf, Arc en Ciel and Balamand). They have different mixing ratios of biomass raw material consisting on pine wood, olive wood, vine wood, apple wood, olive pomace and other types.

The five briquetting plants in Lebanon can be all characterized as demonstration projects as they were funded mostly through grant financing from European development funds (15) (16) (17). To date, in Lebanon, the private sector has not invested independently in the biomass briquetting sector. However, they are involved as operating partners in the briquetting plants of Bkessine, Ankdket and Balamand. The plants have different organizational structures in the sense that the Andket and Bkessine plants operate under a public-private partnership structure and the Balamand plant, which is planned to begin operation in 2019, is run under a university-private-public sector partnership. The Shouf and the Taanayel plants are currently being operated by local NGOs.

The type of equipment used vary between the plants, but the screw type presser is most common, and it is used in all three of the plants in Balamand, Andket and Bkessine. The Shouf plant relies on a pyrolytic furnace that is manufactured in Lebanon and the Taanayel plant uses piston compressing to manufacture its briquettes. The designed output capacity of these plants varies from 0.8 tons/day for the Taanayel plant, 4 tons/day for the Shouf plant and 2.5 tons/day for the Bkessine, Andket and Balamand plants. However, all five plants are currently operating at a lower production than initially designed. The yearly output of the Shouf plant suffers from long periods of low production due to the continuous maintenance and repairs periods due to the low quality of the locally manufactured machinery. In 2017, a total of 600 tons of briquettes each year was produced in the Shouf plant almost half of its designed output capacity. The Taanayel plant on the other hand does not have enough incentives to operate at its maximum capacity due to the expensive cost of production, especially the high labor requirements, and the difficulty to enter in competition with the other heating fuels currently being traded in the Lebanese market, as reported by the operator during a site visit in 2017.

The Bkessine and the Andket plants were operating at low production rates of 250 tons per year during their first two years of operation, however this capacity was doubled to 500 tons per year during the third year of production (2019) when several optimization measures were implemented. The Balamand plant was still being launched during the writing of this paper.

2.1.3. The role of Private-Public Partnership in biomass briquetting process

Two public-private agreements were signed in 2016 between the municipalities of Bkessine and Andket and a private company to operate and maintain the biomass briquetting plants. Municipalities in Lebanon are relying more heavily on grants and donation to finance forestry projects but also to maintain the pruning activities in the forests. Municipalities in Lebanon are often under staffed, operate on a low budget, and their access to finance is limited, especially given the inconsistent transfer of ‘entitled’ funds from the central government. In the biomass sector, public–private partnerships are traditionally forged to pool financial resources, knowledge, experiences and expertise together for successful implementation and management of projects (18) (19).

PPPS are seen as risk reduction tools (20) (21) (22) (23) (24) for the emerging biomass sector in Lebanon. PPPs are seen to decrease certain risks topologies to the forestry biomass sector. Authorization risks, plant reliability and general technology risks, financing risks and biomass contracting risks are all allocated to different partners in the agreement (21). The plant reliability risk and general technology risks can be allocated to the private partner (20).

The private sector is generally thought of as more efficient and can optimize commercial activities of the plant (25). The transfer of the risks of an investment to the private sector is one of the main benefits of a PPP (26) (27). The private sector is usually offered better financing options from financial institutions (25), and this is particularly true in Lebanon where municipalities are not able to secure loan from financial institutions. Additionally, having a private partner can expose the plant to better market conditions especially when it comes to having an allocated budget for marketing, adapting to new market environment and having plans for expansion and export (21). The private sector can have more flexibility when it comes to hiring personal, it does not have the same legal, bureaucratic and sometimes social and political challenges of public recruitment (25). However, the overall difficulty and risk of the project increases drastically if public support is not present (21). In fact, having the municipality as part of the organizational structure (management) of the plants directly decrease the risk of authorization and permitting and in turn lowers the risk of raw material interruption that can cause significant financial losses. Furthermore, the partnership with public sector can lower the financial requirements of biomass projects developments in Lebanon as the public sector owns (communal, municipal, and state-owned) land that cover 40% of the total forestry and other wooded lands in Lebanon (13). Some of these land plots can be offered as in-kind contribution to the PPP agreement lowering the plant investment anywhere between 40-50% of the initial investment.

2.1.4. Biomass process in Bkessine and Andket plants

Accordingly, the two biomass briquetting plants (28) implemented under the CEDRO projects have identical organizational structures, in the sense that similar PPP-agreements between the respective municipalities of Bkessine and Andket and the private contractor were signed. Under these agreements, the municipalities play a key role in providing the necessary raw material for the continuous production of the plants. Having the municipality as part of the partnership eases the issuing of pruning permits from the Ministry of Agricultural (15) and decreases the risk of interrupted supply of agricultural biomass, necessary for briquette compactness and overall quality, by organizing the collection of agricultural residues from local farmers. In addition, the PPP agreement decreased the cost of investment by offered the land required by the briquetting facilities as an in-kind contribution to the project.

In Bkessine the municipality owned an abandoned building that was refurbished to serve the briquetting plant and in Andket the municipality offered a common land suitable for the plant’s construction. In return, in Ankdet, the residents of the area are offered a total of 120 tons of briquettes at a subsidized cost of $250/ton from the plant. In Bkessine, the municipality is offered a price of $40/ton for the raw material pruned in the forest or agricultural residue collected. The private sector is contracted to operate and maintain the plant and is responsible of all hiring and managerial activities. These agreements were tested during the first year of production and were renewed for three additional years as both parties saw benefits in their continuity. However, several operational inefficiencies were highlighted by both parties and are discussed in the section.

Inside the plants, the two plants of Bkessine and Andket have identical processes in the sense same briquetting equipment were installed and intended to operate under the same production capacity of 25 tons per day. Both plants need to rely on the municipalities to conduct pruning and collecting activities related to securing the raw material from the forestry and agricultural residues. The private partner undergoes the task of chipping biomass raw material at source and needs to rely on rented trucks to deliver the raw biomass material to the plants. Once the chipped biomass is delivered to the plant they are stored outside the plant for a period of 1-2 months, subjecting them to extended periods of natural drying. Natural drying consists on exposing the biomass to favorable environmental conditions to reduce the moisture content (28). This process can take as long as 2 months depending on the initial moisture content of the biomass and the natural weather conditions.

During the first year of production (2017), we learned that the natural drying process was taking more time than initially intended, this was due to the raw material being exposed to rain and snow during the winter season causing a cease in production for around 20 working days during the first year, equivalent to a decrease of approximately 50 tons of briquettes from the annual production capacity. In this regard, an external shed was suggested to protect the raw material for more favorable drying conditions and allow for the uninterrupted production of biomass briquettes. The next stage of the process consists of feeding the chipped biomass to a hammer mill that further reduces the size of particles to less 4 mm in diameter. During the first year of production the handling of the raw material was performed by a rented steer loader that was subjected to the availability of its owner. Their availability greatly impacted the continuous production of the plant causing an estimated decrease in production of approximately 50 tons of briquettes per year. The second optimization improvement suggestion was to purchase the plant's own steer loader. The crushed raw material is then transported on conveyor belts to heated tunnels that would further decrease the moisture content of the biomass fuel down to a specified range (between 5% to 15%) suitable to start densification. The heating process consists of circulating the biomass in an externally heated tunnel that subjects the biomass to hot air in direct contact with wood. The drier is fueled by defected briquette (having smaller sizes or not being compact enough). The next stage of the process is compacting or densification, in our case, the briquetting process relies on a screw type piston that pushes the raw material in a chamber that becomes progressively narrower. This technology enables the creation of inner holes in the briquettes thus favoring its later combustion (29). The final product briquettes are then packaged in either small plastic bags that can contain 10 kg of briquettes, and these are sold in retail stores at a price of $500/ton while they are sold at cheaper wholesale prices of around $300/ton in bigger bags that can contain up to 1,000 kg of briquettes. The packaging process was considered labor intensive, requiring the availability of all four employees working at the plant. It forced the plant manager to divide the work load into two shifts: producing the briquettes usually in the morning and packaging in the afternoon. This layout reduced the total production of the plant from the 500 tons per year (the rated capacity of the equipment) by almost half. The purchase of new packaging equipment was then recommended, a pallet wrapping machine and an automatic packaging machine to reduce the operational cost of packaging, labor cost and directly increase the plant's production capacity by eliminating the double shift. The proposed optimization measures are summarized in Table 3.

***Table 3**: Optimization Measure implemented in 2019 at the two Briquettes Plants of Bkessine and Andket*

Areas of Optimization	Optimization Measures	Cost of Measure ($)	Operation before Optimization	Operation after Optimization
Storage	External Shedding	$20,000	250 tons/year	300 tons/year
Packaging	Automated Packaging	$20,000	250 tons/year	500 tons/year
Handling	Steer Loader	$27,000	250 tons/year	300 tons/year
Total	-	$87,000	250 tons/year	500 tons/year

3. METHOD AND DATA SOURCES

3.1. Financial and qualitative appraisal

The two-demonstration projects implemented by the UNDP CEDRO project has enabled a thorough review of the technical, administrative, and policy prospects and barriers of the biomass briquetting industry in Lebanon. A financial appraisal method is used to evaluate the costs and benefits of the biomass briquetting plants. The method is well established in the literature (for example see (30) (31)), and is used to assess various biomass technologies and processes (for example, see (32) (33) (34)). The net present value (NPV) indicator is used to demonstrate the financial viability of such projects. The NPV calculates the difference between the present value of cash inflows and the present value of cash outflow over a period of time, it is generally used to analyze the profitability of a projected investment. The capital expenditure (C_0), cashflow (Cn) as well as the interest rate (r) are the main parameters that affect the NPV (Equation 1).

$$NPV = -C_0 + \frac{C_1}{1+r} + \cdots + \frac{C_n}{(1+r)^n}$$

***Equation 1.** NPV Calculation*

Where

C_0: initial capital investment	Cn: cashflow for year n
r: interest rate assumed 10%	n: total years of the project assumed 20

The data required for the application of the financial appraisal model was collected through an intensive review of information in the literature and several site visits that included semi-structured interviews with the plant managers, the mayors of the respective municipalities and the owner of the implementing private sector contractor. The data obtained from the field, equipment data sheets, own estimates and calculations show significant uncertainties due the fuzziness of the data collection methods and inherent uncertainties of biomass briquetting plants [see Annex 2]. The yearly cashflow of the plants are calculated with reference to (equation 2) and are dependent on the cost of production (F_{OC} and V_{OC}), the plant's production output (Q) and market prices (P).

$$C_n = Q(P - DR - F_{OC} - V_{OC})$$

Equation 2. *Cash Flow Calculation*

Where

Q: production output	P: price of the briquette
F_{oc}: fixed operating cost	V_{oc}: variable operating cost
DR: debt repayment	

3.2. Monte Carlo Simulation: Mitigating the uncertainty risks in financial appraisal models

The capital and operating and maintenance (O&M) costs of briquetting plants can vary significantly depending on location, site specificities, organizational structure and the quality and standards of the technology and/or process. In this regard, a single NPV value will no doubt be inconsistent and not significant enough to guide investment options. Hence, the decision for investment cannot be assessed using a single NPV value but should be studied relying on the Monte Carlo (MC) simulation method for financial appraisal. The Monte Carlo method is a deterministic method that predicts the behavior of a complex mathematical equation by using a random number for multiple calculation iterations. In fact, the MC simulation method has been used as a risk analysis tool aiding managers and decision makers in assessing investment choices through uncertainties reduction (35) (36) (37). The method has been used in optimization forest supply chain by (38) (39) (40). The novelty of this study is the use of Monte-Carlo simulation to overcome the fuzzy dataset related to the cost and production indicators used to appraise biomass briquetting plants under different policy and investment scenarios. In our simulations, we use random sampling in the form of normally distributed probabilistic functions having three main parameters; a maximum value, a minimum value and a mid-point value to calculate the NPV. These include uncertainties from different parameters including the type of investment choice, the cost of production and logistics, the availability of raw material, the cost of electricity, market instability and different financing options. The MC simulation method allows us to produce distinct sets of 1,000 rounds of NPV values corresponding different operating costs, production outputs, financing options and market prices. The set of NPVs are then analyzed with basic statistical tools such as the mean, maximum and minimum values, standard deviation, coefficient of variable three likelihood function (likelihood of making money, likelihood of making profits more than $100,000, likelihood of making profits more than $1,000,000).

3.3. NPV Parameters in biomass briquetting plants: sources of Uncertainty

3.3.1. Initial investment (C_0) options: Three cases of investment options

We aim at testing the financial viability of the plants by simulating the initial investment of briquetting relying on traditional financing option such as equity and debt financing. We assume that in all scenarios, unless specified otherwise, are financed through debt to equity finance ratio structure of 70% debt, 30% equity and an interest rate of 10% for debt financing. Accordingly, and in order to test the effectiveness of the operation measures implemented in year 3, we have developed three distinct initial investment (C_0) scenarios (low, mean, high). The "low investment" scenario duplicates the inefficient plants' operation during the first year of production. The "mean scenario" duplicates the minimum requirements of operational optimization measures implemented, the aim is to duplicate the plants' production during year 3. The "high investment" scenario is a theoretical case where the plant operates at maximum operational efficiency. From the values and parameters described in Annex 2, the total estimated investment cost varies for the three distinct scenarios from $179,000 for "low investment" scenario, to $259,000 for the "mean investment" scenario and $326,200 for the "high investment" scenario. Each investment scenario carries different operational efficiency cost and production outputs discussed in the following sections (table 5).

3.3.2. Yearly cash flow (C_n) parameters

The cash flow of the plants can be broken down to several cost items (Variable O&M, Fixed O&M, Market Prices and Debt Repayment) and is directly affected by the production output of the plant. With respect to the cash outflows of the plants, they can be broken down to several cost sub-categories; (1) harvesting and pruning of the forest cost, (2) transportation of the raw material from the forest or agricultural land to the plant cost, (3) the operation of the process itself which includes (energy cost, labor cost and depreciation), (4) post-production costs, including transportation to distribution centers and points of sale and overhead cost (administration, marketing and advertisement) and (5) debt repayment. The cash inflows of the plant are dependent on market prices and the quantity of briquettes produced. We labeled the several cost sub-category items into two distinct typical operational costs grouping, variable operation and maintenance costs (V_{OC}) and fixed operation and maintenance cost (F_{OC}).

3.3.2.1. Production output (Q)

The yearly production capacity varies under each scenario and are directly linked to the investment choices made at the operational level and initial capital level. Under the "low investment" scenario and without implementing any the optimization measures suggested, the production capacity is limited to 250 tons/year, this means the plant is operating at almost 25% of its designed capacity. The "mean investment" scenario considered the optimization measures discussed (in Section 3.1.2) and results in doubling the plant production to 500 tons/year. The "high investment scenario" considers

optimization measures that follow higher international standards which in turn decrease the cost of maintenance and repairs but also includes more spending on overhead and marketing allowing the plant to operate at almost 93% of its designed capacity for a total yearly capacity of 700 tons per year.

Table 4*. The plant operation characteristics under three investment scenarios*

Initial Investments Scenarios	Initial Cost ($) without PPP	Initial Cost ($) with PPP	Production Output (Q) (tons/year)	Fixed O&M ($/ton)	Variable O&M ($/ton)
1. Low Investment Option (Year 1 and 2)	439,000	179,000	250	215	80 - 105-130
2. Mid-Investment Option (Year 3 Optimization)	519,000	259,000	500	185	
3. High Investment Option (Maximum Optimization)	586,000	326,200	700	155	

3.3.2.2. Fixed operation and maintenance cost (F_{OC})

In terms of fixed O&M costs these depend on the type of investment, more investment means more operational efficiency gains and a decreasing cost of production. Several cost items fall under the fixed O&M cost label, namely, under production costs, this includes labor wages, packaging costs, maintenance and under post-production costs we include delivery and transportation costs and overhead and maintenance. Labor wage are highly dependent on the amount of briquette produced per day as they are based on fixed daily wages. The maintenance cost depends on a variety of criteria namely the age and quality of equipment and the availability of skilled personnel. The last uncertainty is characterized by the overhead cost and marketing efforts which are dependent on uncertain market conditions. For the “low investment” scenario, we calculated a fixed O&M cost of $185/ton and production output of 250 tons of briquettes per year. For the “mean investment” scenario we calculated a fixed O&M cost of $140/ton and production output of 500 tons of briquettes per year. For the “high investment” scenario we calculated a fixed O&M cost of $105 per tons and a production output of 700 tons.

3.3.2.3. Variable operation and maintenance cost (V_{OC})

The remaining operational cost parameters are stochastic (inherently variable) and depend on various operating condition. The cost of raw material varies between $40-60 per ton depending on accessibility of pruning area to nearby roads and the density of the forest in the pruning location. The transportation and logistics costs vary between $20-30 per ton of briquettes depending on the distance of the raw material from the plant (5-20km). Other production and operational uncertainties are characterized by the unpredictability of electricity outages which directly impacts cost of production, these differ greatly between geographical locations in Lebanon, the time of day but also the season since outages are much more common during peak summer loads (EDL, 2015). Energy cost therefore can vary between $20-$40/ton per depending if the plant is running on EDL electricity or diesel genset. Variable O&M cost items are independent to all investment scenarios and vary between 80$/tons of briquettes produced and 130$ per ton of briquettes produced.

3.4. Sensitivity analysis

3.4.1. Market price (P)

To add to the already challenges task of calculating the biomass briquetting’s NPV, the price of the output briquettes varies as well. The uncertainty of the market is analyzed under each scenario with a variability in prices ranging from $250/ton to $500/ton (table 6.). The lowest value of market price represents the price of briquettes sold in whole sale (>1 ton) at factory gate. The briquettes are also sold at whole sale price at different selling points with values varying between $300-$400 depending on the distance of delivery to the customer. And finally, a retail price currently set at $500/ton where briquettes are sold in bags of 10 kg for a price of 5$ per bag. The quantity of each type of type of selling options is widely uncertain as they depend on market conditions, weather (harsh vs. mild winters), competing fuel prices, lack of adequate monitoring and logging, the distance of delivery, the success of marketing campaigns and consumer awareness. For the NPV calculations, the market prices in all scenarios follow a random distribution varying between ($250-$500/ton). We considered three sensitivity analysis for varying market price. This price simulation considers a market price subsidy option provided by the government on each ton of briquette sold. For the purpose of this study we considered three types of subsidies, namely, a $25/ton subsidy, a $50/ton subsidy and a $100/ton subsidy.

Table 5. *Uncertainty in the market price of briquettes in Lebanon*

Market Prices (P) ($/ton)	No Intervention	$25/ton Subsidy	$50/ton Subsidy	$100/ton Subsidy
Wholesale price - Factory gate	250	275	300	350
Wholesale price - delivery	300-400	325-425	350-450	425-525
Retail price	500	525	550	600

3.4.2. Financing options (interest rates (r) and debt repayment (DR))

There are three financing options available for the briquetting market in Lebanon. The first option is through commercial-private financial institutions, the second is through grant financing and the third is through soft loans[10].

[10] In Lebanon as of 2019, there are currently three such mechanisms for soft loans; NEEREA (http://lcec.org.lb/en/NEEREA/AboutUs), LEEREFF (https://leereff.com/), & EBRD GEFF (https://ebrdgeff.com/).

The interest rate of private financial institutions loans in Lebanon are 10%, the repayment period is usually 8 years. We consider for all investment options a (70-30%) debt to equity ratio. The second financing option is the most common financing instrument used to finance briquetting plants in Lebanon. In fact, as shown in this paper, all the briquetting plants in Lebanon are financed through international donations. These donations sometimes cover all the investment, but partial investments are also common. For the partial financing options, we consider that the remainder amount is financed through a 70% debt to 30% equity ratio, with the interest rates and loan structuring of private financing institutions. The third financing option duplicates the structure of soft loan, a subsidized loan provided to energy efficiency and renewable energy projects in Lebanon. This loan offers a much lower interest of 2.5% and a grace period of 2 year.

Table 6. *Financial and Market Price Indicators of Policy Intervention*

Financing Options	Debt to equity ratio	Interest rate (r)	Grace Period	Debt Repayment Period
PPP (No-Intervention)	70%	10%	-	8 years
Soft loan	70%	2.25%	2 years	10 years
Partial Cash Grant	70%	10%	-	8 years
Full Cash grant	N/A	N/A	-	N/A
$25/ton subsidy	70%	10%	-	8 years
$50/ton subsidy	70%	10%	-	8 years
$100/ton subsidy	70%	10%	-	8 years

Seven different policy scenarios are studied to provide a broad economic analysis of the biomass briquettes market in Lebanon. The financial and market price indicators of the "PPP (No Intervention)" scenario serve as a benchmark for comparing the benefits of the different policy interventions discussed in this paper. The mean NPV of 1,000 rounds of Monte Carlo simulation will serve as the main financial indicator for assessing the different financing options of Table 5. The standard deviation, and more importantly the coefficient of variance, is used to discuss the significance of the interpretations. The likelihood of gaining money or the percentage share of negative NPVs from the 1,000 NPV simulations is discussed when the mean NPV is not indicative in the discussion. Additionally, total government expense or the cost of the policy intervention is mentioned when two policy options show similar impacts on the mean NPV. Finally, a market analysis is used to summarize the results and recommend policy interventions.

4. RESULTS AND DISCUSSION

4.1. Policy options targeting initial investment (I_0)

4.1.1. Analysis of PPP Impacts on NPV results – Bench mark Scenario

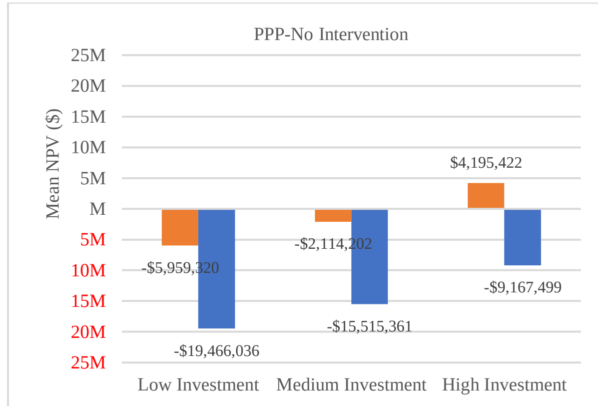

Figure 1*. Mean NPV of 1,000 rounds of Monte Carlo Simulation showing the added benefits of PPP agreements and Optimization for briquetting plants of Bkessine and Andket,*

The results shown in (Figure 1) verify the clear benefits of the optimization measures implemented in year 3, and they also show the benefits of PPP agreements in decreasing the initial cost of investment and their effects on mean NPV. In all three investment scenarios the PPP agreements improves the mean NPV of the 1,000 MC simulations. In fact, all investment options low, medium and high are not replicable without signing PPP agreements. This means that the current plants operation at Bkessine and Andket (even with optimization measures introduced in year 3) cannot be financially viable without further intervention by policy. The plant needs to increase its output to reach at least 700 tons per year to become suitable for loans from private financial institutions.

4.1.2. Analysis of full grant impacts on NPV

The plants of Bkessine and Andket were funded by full cash grants, and this scenario shows positive mean NPVs for all investment scenarios when capital investment in secured from grant donations (Figure 2).

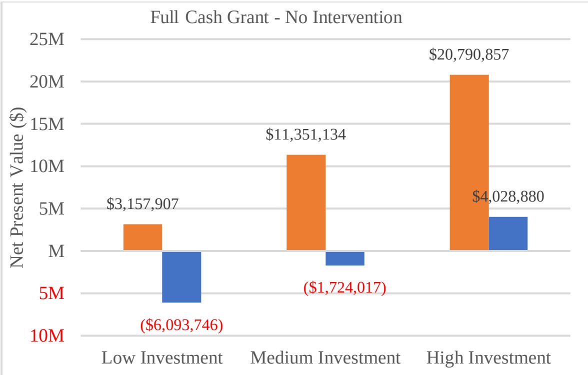

Figure 2. *Comparing Mean NPVs of 1,000 rounds of Monte Carlo Simulations of the Full Grant Investment Option to the No Intervention Option*

It should be noted however that this model of grant financing does not encourage operational efficiency measures. The plant owner/operator does not have enough incentive to opt for optimizing some of their machinery or processes since their plant are able to sustain themselves as long as there are no debt repayments. It is also the case that grant financing should be seen as seed financing to promote the maturity of this technology and service to the commercial extent where it does not require support.

4.1.3. Analysis of partial grant impacts on NPV

When we consider that half of the initial investment needed is granted from donors and the other half is funded through a debt and equity ratio of 70-30%, the result is a positive NPV for the medium and high investment options and the a negative for the low investment option (figure 3).

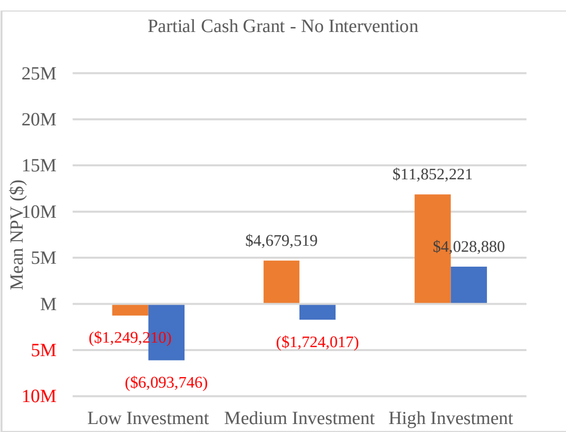

Figure 3*. Comparing Mean NPVs of 1,000 rounds of Monte Carlo Simulations of the Partial Grant Investment Option to the No Intervention Option*

The results confirm that the low investment scenario is not sustainable with a 50% grant component. The results of the simulation confirm the necessity of implementing optimization measure especially the ones targeted at increased production outputs.

4.1.4. Analysis of soft loans impacts on NPV

The soft loan simulation results (Figure 4) are very similar to the partial grant investment scenario where the mean NPVs of the two simulations are almost identical with a slightly higher NPV means for the partial grant option.

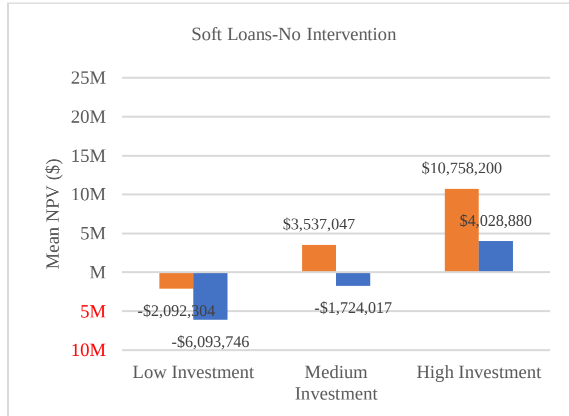

Figure 4*. Comparing Mean NPVs of 1,000 rounds of Monte Carlo Simulations of the Soft Loan Investment Option to the No Intervention Option*

Indeed, the favorable structure of the loan (low interest rates and 2-year grace period) are enough for a successful plant operation after optimization (medium and high investment options). The low investment option still provides a negative mean NPV and is considered risky for loan financing. The soft loan policy options should be considered as the most favorable from the government's perspective since it has been operation in the past (2011-2018), however it was never applied to include biomass briquette investments. There are no clear restrictions on the type of investment is granted under the NEEREA loan however to date in has only granted loans to solar PV investment, solar water heaters investment and energy efficiency in buildings.

4.2. Policy options targeting market prices

4.2.1. Analysis of cash subsidies impacts on NPV

In this section, market price variations are analyzed for their impacts on the plant's performance, the results ($25 and $50 subsidies) simulations are shown in (Figure 5).

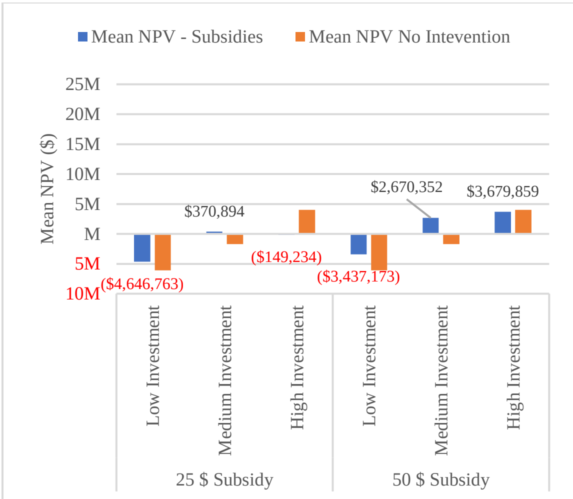

Figure 5. *Comparing Mean NPVs of 1,000 rounds of Monte Carlo Simulations of the $25 and $50 Subsidy Options to the No Intervention Option*

The results show improvement on the mean NPVs for the low and medium investment options when cash subsidies are applied. However, the 1,000 rounds of simulation are not enough to capture the effects on the mean NPV of increasing for the "high investment scenario". This shows a clear need for more rounds of simulations especially for the case of the "high initial investment" scenario. When the plant's output increases to 700 tons of briquettes per year the sensitivity to the prices of briquettes becomes much more apparent. This is confirmed when looking at the standard deviation and the coefficient of variation of the "high" investment scenario compared to the other two investment options (Annex 3).

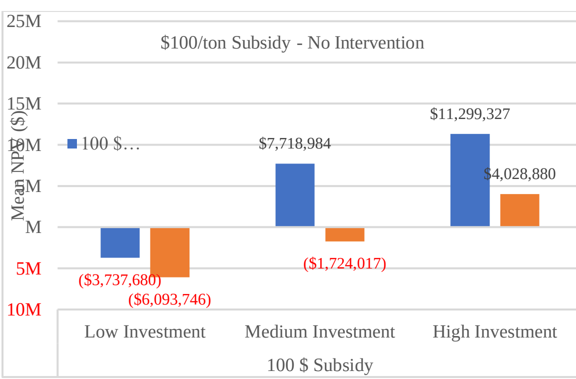

Figure 6. *Comparing Mean NPVs of 1,000 rounds of Monte Carlo Simulations of the $100 Subsidy Option to the No Intervention Option*

The $100 market subsidy (Figure 6) shows clear improvements of mean NPVs for all three investment scenarios. Under this scenario the "medium investment" option is the highest among the different simulation excluding the "full cash grant". However, it should be noted that the cost of the program is five times more expensive in terms of policy cost when compared to the soft loans scenario for example.

4.2.2. Analysis of market prices and market demand

The prices of briquettes are compared to the prices of other competing heating fuels in Lebanese market in (Figure 7) to provide a better understanding of market demand.

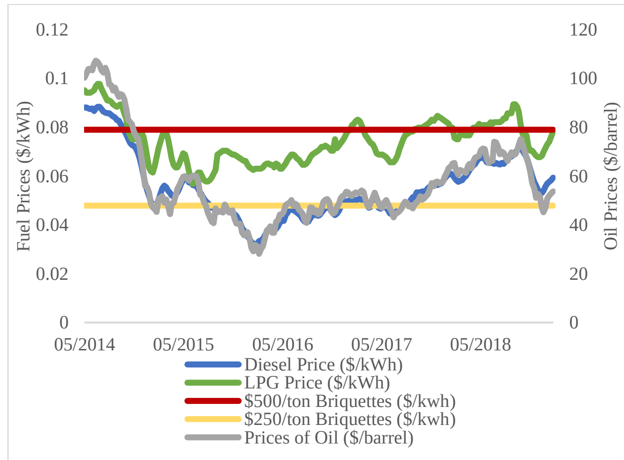

Figure 7. *Weekly market prices of the most common fuels used for heating in Lebanon (2014-2019) compared to the prices of briquettes produced by Bkessine and Andket*

The data collected shows the price of briquettes sold at whole sale at factory gate was in fact cheaper than diesel fuel for most weeks during of the last five years (2014-2019). However, the high price of briquettes sold at retail stores cannot compete with the other heating fuels when the price of barrel of oil is lower than $70/barrel. For this reason, we performed a last round of simulations duplicating the soft loan with two different maximum prices of briquettes sold in retail.

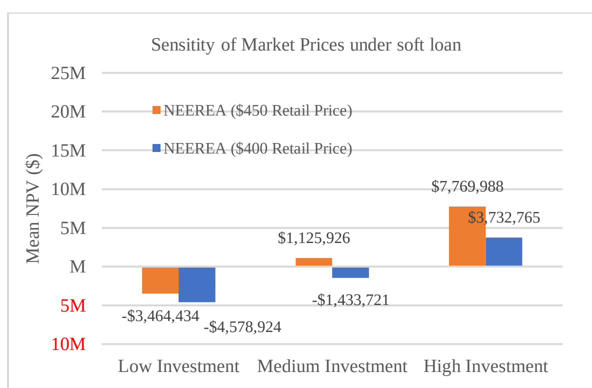

Figure 8. *Sensitivity of Market Prices Under NEEREA loan simulation*

In (Figure 8) we explore the performance of the plant with two lower market prices for retail ($400-$450/ton). In the case of limiting the retail price to $400/ton the results show only positive mean NPVs for the "high investment scenario" and negative NPVs for the "medium" and "low" investment scenarios. In the case of limiting the price of retail to $450 the medium and high scenario show positive and NPV and the low remains showing negative values. Consequently, under current market conditions and plant performance "medium scenario investment" the price of briquettes sold in retail stores cannot go below $450/ton.

5. CONCLUSION AND POLICY RECOMMENDATIONS

In conclusion, the two demonstration projects of briquetting plants in Bkessine and Andket are essential for the development of the briquetting market in Lebanon. Financing pilot projects proved to be essential for the development of the nascent briquetting market in Lebanon. The two biomass projects funded by European Union served as case studies for testing the importance of PPP agreements for producing biomass briquetting from forestry and agricultural residues, the importance of optimization measures under current market conditions and the need for policy intervention. In fact, the grant financing option is extremely important for developing pilot projects to allow such analysis, but it should not be considered as a financing option for new briquetting plants as they proved to suppress optimization measures implementations and adaptation to new market conditions.

The Monte Carlo simulation proved to be essential tool for simulating financial appraisal models with uncertain data and for modeling different scenario outcomes. However, some of the limitations of the method highlighted in this study call for improvements. The 1,000 rounds of NPV results was deemed too low when the output of the plant was increased to 700 tons of briquettes per year in the "high investment scenario". In fact, increasing the rounds of simulating was computationally challenging for the excel model built for this simulation analysis. Furthermore, some of the uncertainty parameters in the plant's performance (such as the quantity of briquettes sold at different market prices) could be improved by better monitoring and data collection methodologies. This can be enforced by improving the administrative laws governing PPP agreements in Lebanon.

The continuation of soft loan systems supporting renewable energy investment should be considered a priority to support the briquetting market as the favorable loan condition help guarantee the financial performance of the plant. Policy Interventions targeting market prices proved to be not as effective as policy interventions targeting initial investments. We conclude that the policies targeting market prices (cash subsidies or by the same logic carbon taxes) should not be implemented in the short term. A more cautious approach would be to increase the level of awareness of Lebanese consumers concerning briquette production in Lebanon by highlighting their positive environmental performance, their positive contribution to decreasing forest fires and their positive contribution to rural employment and development.

6. FUTURE WORK

- Increase sampling rounds to more than 1,000 simulations and improve simulation model
- Conduct Life Cycle Assessment to quantify the environmental performance of briquettes compared to other heating fuels.
- Quantify the reduction of fire risk from the implementation of briquetting plants.
- Incorporate more uncertainty parameters (quality of briquettes) in the assessment
- Improve monitoring and data collection methodologies

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Annex 1: Briquette Properties in comparison to the EN-14961-3 Standard, Results from AUB Environment Core Lab (2018)

***Table 7**. Metal Analysis of Andket Briquettes*

Element	Unit	EN 14961-3	Briquettes Results	Method	UR
Arsenic	mg/kg	<1	<0.05	EPA 200-7/8 M	R±16% of R
Cadmium	mg/kg	<0.5	0.13	EPA 200-7/8 M	R±30% of R
Chromium	mg/kg	<10	1.5	EPA 200-7/8 M	R±27% of R
Copper	mg/kg	<10	14	EPA 200-7/8 M	R±31% of R
Lead	mg/kg	<10	<0.05	EPA 200-7/8 M	R±39% of R
Mercury	mg/kg	<0.1	0.79	EPA 200-7/8 M	R±27% of R
Nickel	mg/kg	<10	1.1	EPA 200-7/8 M	R±23% of R
Zinc	mg/kg	<100	19	EPA 200-7/8 M	R±24% of R

***Table 8**. Analysis based on wet weight Sample Result (R) Method of Andket Briquettes*

Analysis based on wet weight	EN 14961-3	Briquettes Results	Method
Total Carbon (%)	-	44.8%	Thermofinnigan- High Combustion
Total Hydrogen (%)	-	6.02%	Thermofinnigan- High Combustion
Total Nitrogen (%)	<0.3	1.09%	Thermofinnigan- High Combustion
Total Sulfur (%)	<0.03	<0.7%	Thermofinnigan- High Combustion
Calorific Value G.H.V.	-	5760.7 Kcal/ Kg	By Calculation
Calorific Value N.H.V.	-	5450.9 Kcal/ Kg	By Calculation

Annex 2: Detailed Cost Scenarios for Briquetting plants in Lebanon (the case of PPPs)

Table 9. *Detailed Description of Initial Cost Parameters*

Initial Cost ($)		Before Optimization	After Optimization		Comments
		Min	Mean	Max	
Equipment	Briquetting Equipment	38,500			Only European Standards Accepted
	Rotary screen	5,700			These are heavy equipment materials with minimal electric and mechanical part, Chinese model are accepted.
	Conveyors	15,000			These are heavy equipment materials with minimal electric and mechanical part, Chinese model are accepted.
	Shredder/hammer mill	17,000			These are heavy equipment materials with minimal electric and mechanical part, Chinese model are accepted.
	Dryer	18,000			These are heavy equipment materials with minimal electric and mechanical part, Chinese model are accepted.
	Mobile chipper	25,000			Only European Standards Accepted, but a plant could be equipped with a bigger chipper
	Packaging Equipment	0	20,000	50,000	No Packaging would decrease labor productivity, mean is Chinese models, max is European models
	Installations	10,000-15,000-20,000			Depending on the contractor if the operator of the plant or not. Min Cost is under PPP agreement.
	Steer Loader	0	27,000	40,000	No Bobcat would decrease labor productivity, range of prices in the market depending on manufacturer
	Transport Vehicles	40,000	50,000	60,000	Depending on the size of the trucks, bigger trucks would lower transportation cost
Land	Land rent costs (per year) with storage area	0-6,000-12,000			Area required: from 500 to 2000m2. Land cost will vary for each region in Lebanon. Municipal land shall be given free of charge to increase feasibility and provide jobs in the area. Min is PPP agreement
Building and Storage	Plant building	10,000	13,000	17,000	Minimum cost for a building of 25*11m. Maximum cost for 25*25m
	Storage	0	20,000	30,000	Depending on the size of the storage, storage space is sometimes provided by the municipality as part of the building

Total Initial Cost	157200	245,200	326,200	The minimum cost is for an all equipment from Chinese origin. The maximum cost is for all equipment from European origin. The mean is for a mix of China and Europe origin

Table 10. *Detailed Description of Fixed (O&M) Parameters*

Fixed O&M Cost ($/ton)		Before Optimization	After Optimization		Comments
		Max	Mean	Min	
Production Cost	Labor Wages	120	90	70	Low investment, low automation will result in higher labor cost. High initial investment will result in lower labor cost as a result of increased daily production.
	Packaging	15	10	5	Manual packaging is maximum cost. Automatic packaging is minimum cost
	Maintenance Costs	10	15	10	Depending on the skilled personnel available and the quality of equipment.
Post Production Fixed Cost	Transportation and Distribution	50	40	30	Depending on distance between plant and distribution. As well as transportation truck capacity. Investment in larger trucks and efficient logistics will result in lower transportation cost.
	Overhead (marketing and logistics)	20	30	40	Depending on marketing effort required and market readiness.
Total Fixed O&M Cost		215	185	155	
Production Volume	Tons/year	250	500	500-700	The low initial investment does not allow to produce more than 250 tons of briquetted per year. Improvements in the plant's operation increases production outputs to reach 700 tons.

Table 11. *Detailed Description of Variable O&M Parameters*

Variable O&M		Min ($/ton)	Mean ($/ton)	Max ($/ton)	Comments
Variable Production Cost	Harvesting and Pruning (cost of raw material)	40	50	60	Short distance from road with harvesting without pruning is minimal cost. Dense forest with long distance to road plus additional pruning is maximum cost
	Transportation (Forest to Plant)	20	25	30	Distance from harvesting area to briquette plant will affect the transportation cost
	Electricity Cost	20	30	40	Low represents full electricity supplied by EDL with adjusted tariffs of $c12/kWh and maximum represent full operation on diesel with current cost of $c24/kWh
Total Variable O&M ($/ton)		80	105	130	
Uncertainty in Market Prices ($/ton)		250	375	500	Min is wholesale (>1ton) on factory gate, Mean is wholesale (>1 ton) plus transportation cost, Max is retail

Annex 3: Results of Monte Carlo Simulation for the Financial Appraisal Model under the different Policy Intervention Scenarios

	Scenarios	Mean NPV	Std NPV	CV	Payback Period*	Percentage of Gaining Money
NO Intervention	Low Investment	($19,650,174)	$3,555,191	-18%	-	0.0%
	Medium Investment	($15,973,214)	$6,689,673	-42%	15.47	0.0%
	High Investment	($9,325,412)	$9,701,787	-104%	12.71	20.1%
PPP	Low Investment	($6,093,746)	$3,363,778	-55%	14.31	2.1%
	Medium Investment	($1,724,017)	$7,289,468	-423%	9.56	43.4%
	High Investment	$4,028,880	$9,740,186	242%	7.33	63.9%
Partial Cash Grant	Low Investment	($729,183)	$3,412,590	-468%	6.84	41.8%
	Medium Investment	$5,142,852	$7,036,754	137%	3.91	73.5%
	High Investment	$12,716,543	$9,465,037	74%	3.24	89.8%
Full Cash Grant	Low Investment	$3,211,457	$3,431,760	107%	6.96	78.8%
	Medium Investment	$11,360,199	$6,897,487	61%	-	95.9%
	High Investment	$20,612,771	$9,834,870	48%	-	100.0%
Soft Loan	Low Investment	($1,908,627)	$3,633,205	-190%	7.75	34.0%
	Medium Investment	$3,533,913	$6,835,410	193%	4.11	66.0%
	High Investment	$10,670,669	$9,551,148	90%	2.92	83.4%
25 $ Subsidy	Low Investment	($4,646,763)	$3,474,363	-75%	14.05	10.6%
	Medium Investment	$370,894	$7,191,639	1939%	10.00	51.5%
	High Investment	($149,234)	$9,851,477	-6601%	8.19	48.9%
50 $ Subsidy	Low Investment	($3,437,173)	$3,498,013	-102%	12.45	21.5%
	Medium Investment	$2,670,352	$6,912,379	259%	7.98	63.2%
	High Investment	$3,679,859	$9,646,827	262%	7.31	63.2%
100 $ Subsidy	Low Investment	($3,737,680)	$3,362,325	-90%	12.13	16.3%
	Medium Investment	$7,718,984	$6,909,829	90%	5.95	83.4%
	High Investment	$11,299,327	$9,538,117	84%	5.92	85.5%

*Table 12. Summary Results of Simulations (Part 1) * Mean Pay pack Periods are only calculated for positive NPV rounds*

Table 13. Summary Results of Simulations (Part 2)

	Scenarios	Revenue >100 K	Revenues > 1 M $	Price > Cost of Production	Cost of Policy over life time ($)	Monthly Debt Repayment (DR) ($)
NO Intervention	Low Investment	0.0%	0.0%	86.1%	$0	$7,104
	Medium Investment	0.0%	0.0%	98.9%	$0	$8,394
	High Investment	19.7%	16.6%	100.0%	$0	$9,478
PPP	Low Investment	1.5%	0.3%	86.2%	($135,000)	$2,898
	Medium Investment	43.3%	40.1%	98.2%	($197,000)	$4,189
	High Investment	63.5%	60.7%	100.0%	($260,000)	$5,276
Partial Grant	Low Investment	41.2%	34.7%	88.0%	($314,200)	$1,271
	Medium Investment	72.9%	68.3%	98.2%	($456,200)	$1,918
	High Investment	89.6%	87.7%	100.0%	($586,200)	$2,638
Full Cash Grant	Low Investment	78.1%	69.4%	86.7%	($666,970)	$0
	Medium Investment	95.7%	93.4%	98.8%	($785,844)	$0
	High Investment	100.0%	99.6%	100.0%	($896,569)	$0
Soft Loan	Low Investment	32.8%	25.3%	86.5%	($224,600)	$1,562
	Medium Investment	65.5%	61.1%	98.8%	($326,600)	$2,261
	High Investment	83.0%	80.4%	100.0%	($434,100)	$2,847
25 $ Subsidy	Low Investment	10.0%	4.3%	93.9%	($260,000)	$2,895
	Medium Investment	51.4%	47.4%	100.0%	($447,000)	$4,189
	High Investment	48.4%	45.5%	99.7%	($609,238)	$5,276
50 $ Subsidy	Low Investment	20.3%	13.4%	99.2%	($385,000)	$2,895
	Medium Investment	62.5%	57.5%	100.0%	($697,000)	$4,189
	High Investment	63.0%	60.3%	100.0%	($958,925)	$5,276
100 $ Subsidy	Low Investment	15.4%	9.3%	94.4%	($635,000)	$2,895
	Medium Investment	83.0%	79.7%	100.0%	($1,197,000)	$4,189
	High Investment	85.4%	82.8%	100.0%	($1,660,000)	$5,276

Annex 4: Policy Cost and Mean NPV of Investment Options

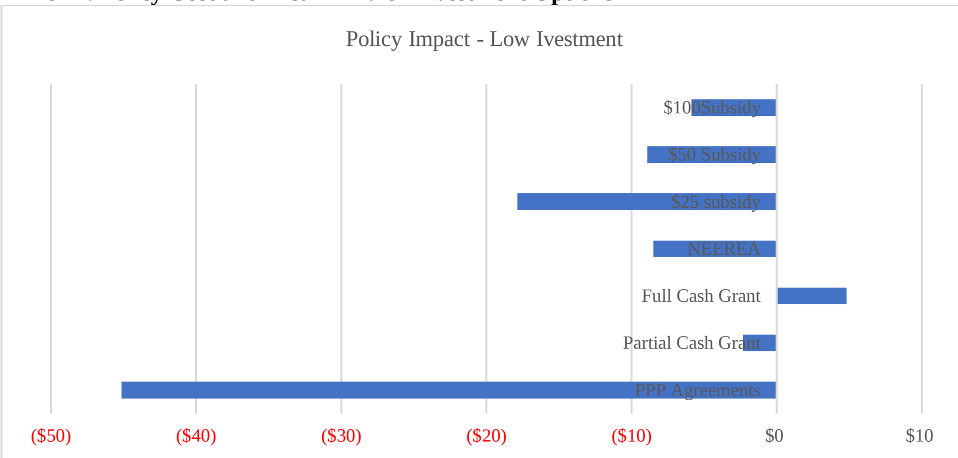

Figure 5. *Policy Impact on mean NPV results for the "low investment scenario"*

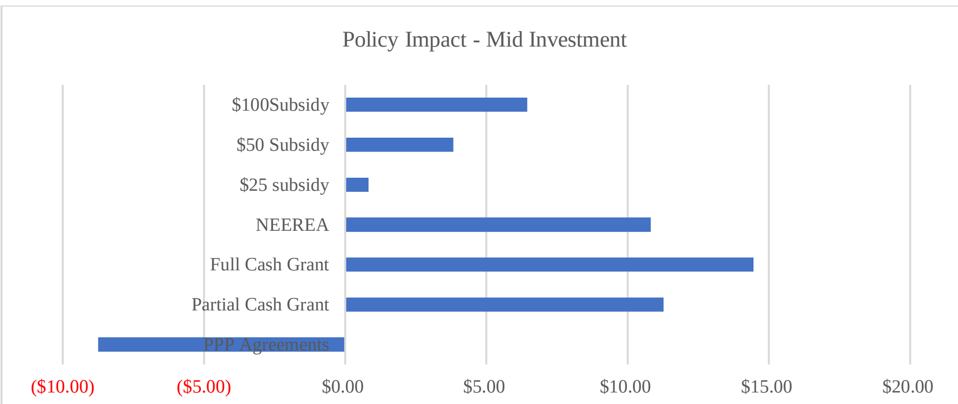

Figure 6. *Policy Impact on mean NPV results for the "mid- investment scenario"*

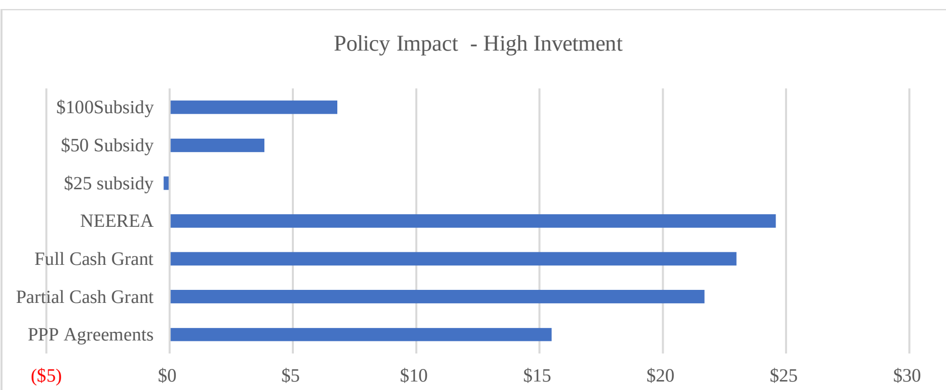

Figure 7. *Policy Impact on mean NPV results for the "high investment scenario*

Annex 5: Briquetting Plants in Lebanon

Table 14. Briquettes producers in Lebanon, 2017

Biomass Briquette Plant	Organizational Structure	Raw Material Used	Mixing Ratio	Briquetting Equipment Used	Briquettes Dimension	Output Capacity	Yearly Production (2017)	Selling Price	Man-Power Required
Andket	Public-Private Partnership	Pine, apple, vine, olives	85%, 5%, 5%, 5%	Screw Press	D: 7 cm L: 30 cm	2.5 tons/day	250 tons per year	250-300$	4 Workers 1 Manager
Bkessine	Public-Private Partnership	Pines, vines and olives	85%, 10%, 5%	Screw Press	D: 7 cm L: 30 cm	2.5 tons/day	250 tons per year	250-300$	4 Workers 1 Manager
Shouf	NGO	Forest, Fruits trees and Olive pomace	25%, 17%, 58%	Pyrolytic Furnace	D: 10 cm L: 35 cm	4 tons/day	600 tons per year	167$ @ factory gate	6 Workers
Balamand	University – Private-Public Partnership	Olive pruning residues Pruning residues from public forests (mainly oak)	95%, 5%	Screw Press	D: 7 cm L: 30 cm	2.5 tons/day	0 tons per year (under construction)	200-210$ (results from feasibility study, to be updated based on plant operation)	4 Workers 1 Manager
Taanayel	NGO	All types of pruning: grapes, apples and forest trees	Dependent on seasonal availability	Piston Compression	D:7 cm L: 30 cm	0.8 tons/day	20 tons per year	<250$	5-10 workers, depending on process.